Measurements of Heavy Meson Lifetimes with Belle

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Abstract

Charmed and beauty meson lifetimes have been measured using 2.75 fb^{-1} (D mesons) and 5.1 fb^{-1} (B mesons) of data collected with the Belle detector at KEKB. The results are $\tau(\overline{B}^0) = (1.50 \pm 0.05 \pm 0.07)$ ps, $\tau(B^-) = (1.70 \pm 0.06^{+0.11}_{-0.10})$ ps, $\tau(D^0) = (414.8 \pm 3.8 \pm 3.4)$ fs, $\tau(D^+) = (1040^{+23}_{-22} \pm 18)$ fs and $\tau(D_s^+) = (479^{+17+6}_{-16-8})$ fs, where the first error is statistical and the second error is systematic. The lifetime ratios are measured to be $\tau(B^-)/\tau(\overline{B}^0) = 1.14 \pm 0.06^{+0.06}_{-0.05}$, $\tau(D^+)/\tau(D^0) = 2.51 \pm 0.06 \pm 0.04$ and $\tau(D_s^+)/\tau(D^0) = 1.15 \pm 0.04^{+0.01}_{-0.02}$. The mixing parameter y_{CP} is also measured to be $y_{CP} = 0.03^{+0.15+0.05}_{-0.18-0.08}$ for $\overline{B}^0$ and $y_{CP} = (1.0^{+3.8+1.1}_{-3.5-2.1})\%$ for D^0, corresponding to 95% confidence intervals, $-0.36 < y_{CP} < 0.35$ and $-7.0\% < y_{CP} < 8.7\%$, respectively. All results are preliminary.

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Measurements of individual heavy meson lifetimes provide useful information for the theoretical understanding of heavy meson decay mechanisms. In particular, experimental results[1] yield $\tau(D_s^+)/\tau(D^0) = 1.191 \pm 0.024$, which is inconsistent with the theoretically expected range[2] of 1.00–1.07. Moreover, measurements of the differences of lifetimes for neutral mesons decaying into CP-mixed states and CP-eigenstates can be used to study the $y \equiv \Delta\Gamma/2\Gamma$ and $x \equiv \Delta M/\Gamma$ particle-antiparticle mixing parameters.

The parameter y_{CP}, defined as

$$y_{CP} \equiv \frac{\Gamma(\text{CP even}) - \Gamma(\text{CP odd})}{\Gamma(\text{CP even}) + \Gamma(\text{CP odd})}$$

is related to y and x by the expression

$$\begin{aligned} y_{CP} &= \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1 \\ &\approx y\cos\phi - \frac{A_{mix}}{2} x \sin\phi, \\ y_{CP} &= 1 - \frac{\tau(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}, \overline{B}^0 \to D\pi)}{\tau(\overline{B}^0 \to J/\psi K_S)} \\ &\approx y\cos 2\phi_1, \end{aligned}$$

where $\phi(\phi_1)$ is a CP-violating weak phase due to the interference of decays with and without mixing, and A_{mix} is a state-mixing CP-violating parameter ($A_{mix} \approx 4\mathcal{R}e(\epsilon)$). The FOCUS experiment reports $y_{CP} = (3.42 \pm 1.39 \pm 0.74)\%$[3], while CLEO gives $y' \cos\phi = (-2.5^{+1.4}_{-1.6})\%$[4], $x' = (0.0 \pm 1.5 \pm 0.2)\%$ and $A_{mix} = 0.23^{+0.63}_{-0.80}$ using $D^0 \to K^+\pi^-$, where $y' = y\cos\delta - x\sin\delta$ and $x' = x\cos\delta + y\sin\delta$; δ is a strong phase between $D^0 \to K^+\pi^-$ and $\overline{D}^0 \to K^+\pi^-$ decays. These results may be an indication of a large $SU(3)$-breaking effect in $D^0 \to K^\pm\pi^\mp$ decays[5].

This report mainly describes the $\overline{B} \to D^*\ell^-\overline{\nu}$ analysis. The D lifetime analyses are described in Ref. 6.

Candidate $\overline{B} \to D^*\ell^-\overline{\nu}$ decays are selected by applying kinematic constraints on events with a lepton and a $D^* \to D^0\pi$ decay chain, where $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$ decays are used. First, the D^0 decay vertex is determined and then the decay vertex of the $\overline{B} \to D^*\ell^-\overline{\nu}$ candidate is calculated using the lepton and the inferred D^0 track. The vertex point of the accompanying B meson is determined from the remaining tracks, after the rejection of K_S daughters and badly measured tracks. When the reduced χ^2 of the vertex fit is worse than 20, the track that gives the largest contribution to the χ^2 is removed and the vertex fit is repeated. This procedure is iterated until the χ^2 requirement is satisfied. Since the method does not properly treat displaced charm vertices and their daughter tracks, a degradation of the vertex resolution and a bias on the vertex position is introduced. An interaction point constraint is applied to the vertex fit for both B mesons in order to improve the vertex resolution. The typical Δz resolution is 100 μm. The proper-time difference is approximated as $\Delta t \approx \Delta z / c(\beta\gamma)_\Upsilon$ where $(\beta\gamma)_\Upsilon$ is $\beta\gamma$ of the $\Upsilon(4S)$ in the laboratory frame.

The likelihood function for $\overline{B} \to D^*\ell^-\overline{\nu}$ lifetime fit is defined as

$$\begin{aligned} & L(\tau_0, \tau_-, S_t, f_t, S_{BG}, \mu_{BG}, \lambda_{BG}, f_{\lambda BG}) \\ & \quad = \prod_i \int_{-\infty}^{\infty} d(\Delta t')[p^i_{SIG}(\Delta t') + p^i_{BG}(\Delta t')], \end{aligned}$$

$$\begin{aligned} p^i_{SIG}(\Delta t') &= (f^i_0 \frac{e^{-\frac{|\Delta t'|}{\tau_0}}}{2\cdot\tau_0} + f^i_- \frac{e^{-\frac{|\Delta t'|}{\tau_-}}}{2\cdot\tau_-}) \\ & \quad [(1-f_t)\frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu)^2}{2\sigma_i^2}}}{\sqrt{2\pi}\sigma_i} + f_t \frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu_t)^2}{2(\sigma^i_t)^2}}}{\sqrt{2\pi}\sigma^i_t}], \\ p^i_{BG}(\Delta t') &= \sum_k f^i_k \frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu^k_{BG})^2}{2(S^k_{BG}\sigma_i)^2}}}{\sqrt{2\pi}S_{BG}\sigma_i} \\ & \quad [(1-f^k_{\lambda BG})\cdot\delta(\Delta t') + f^k_{\lambda BG}\frac{\lambda^k_{BG}}{2}e^{-\lambda^k_{BG}|\Delta t'|}], \end{aligned}$$

where: τ_0 and τ_- are the $\overline{B}^0$ and B^- lifetimes; σ_i and σ^i_t are the main and tail parts of the Δt resolution calculated event-by-event from the track error matrix as described below; f_t denotes the fraction of the tail part of the signal resolution function and is determined from the fit. μ and μ_t are the biases due to the charm meson daughter tracks, determined from the MC simulation; S_{BG}, μ^k_{BG}, λ^k_{BG}, $f^k_{\lambda BG}$ are background-shape parameters, determined from the fit (fake D^*), data (fake lepton) or MC (random $D^*\ell$); f^i_0, f^i_- and f^i_k are fractions of the $\overline{B}^0$ and B^- signals and background contributions that are calculated event-by-event using the measured ΔM_{D^*} value. The $\overline{B} \to D^* X \ell^-\overline{\nu}$ background fractions are estimated from the known branching fractions and included in f^i_0 and f^i_-, since the effect of the missing X is found to be negligible.

The Δt resolution is a convolution of the Δz resolution and the error due to the kinematic approximation ($\Delta t \approx \Delta z/c(\beta\gamma)_\Upsilon$) σ_K:

$$\sigma_i^2 = [\sigma_{\Delta z}/c(\beta\gamma)_\Upsilon]^2 + \sigma_K^2.$$

The Δz resolution $\sigma_{\Delta z}$ is calculated from the vertex resolutions of the reconstructed (σ_z^{rec}) and associated (σ_z^{asc}) B mesons:

$$\sigma^2_{\Delta z} = (S_{det}\sigma_z^{rec})^2 + (S^2_{det} + S^2_{charm})(\sigma_z^{asc})^2,$$

where S_{det} is a global scaling factor that accounts for any systematic bias in the resolution calculation from the track-helix errors, and S_{charm} is a scaling factor to account for the degradation of the vertex resolution of the associated B meson due to contamination of charm daughters. If the reduced χ^2 (χ^2/n) of the vertex fit is worse than 3, the corresponding vertex error (σ_z^{rec} or σ_z^{asc}) is scaled by $[1+\alpha(\chi^2/n-3)]$. This χ^2/n-dependent scaling is essential to account for events with large errors. We use the value of $S_{det} = 0.99 \pm 0.04$ determined from the D^0 lifetime fit in the z direction. The values for σ_K, S_{charm} and α are determined from the MC. σ_t^i is calculated in a similar manner. The associated parameter S_t is determined in the fit along with f_t. Figure 1 shows the $\Delta t_{rec} - \Delta t_{gen}$ distribution and resolution function for MC signal events.

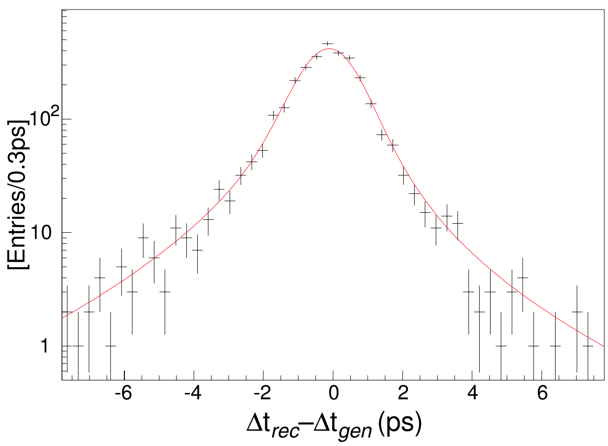

Figure 1: The $\Delta t_{rec} - \Delta t_{gen}$ distribution and resolution function for MC signal events.

The likelihood function for the hadronic modes is defined as

$$L(\tau_{sig}, S_{BG}, S_t^{BG}, \mu_{BG}, \mu_t^{BG}, f_t^{BG}, \lambda_{BG}, f_{\lambda BG}) = \prod_i \int_{-\infty}^{\infty} d(\Delta t')[p_{SIG}^i(\Delta t') + p_{BG}^i(\Delta t')],$$

$$p_{SIG}^i(\Delta t') = (1-f_{BG}^i)\frac{e^{-\frac{|\Delta t'|}{\tau_{sig}}}}{2\cdot\tau_{sig}} [(1-f_t)\frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu)^2}{2\sigma_i^2}}}{\sqrt{2\pi}\sigma_i} + f_t\frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu_t)^2}{2(\sigma_t^i)^2}}}{\sqrt{2\pi}\sigma_t^i}],$$

$$p_{BG}^i(\Delta t') = f_{BG}^i[(1-f_t^{BG})\frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu_{BG})^2}{2(S_{BG}\sigma_i)^2}}}{\sqrt{2\pi}S_{BG}\sigma_i} + f_t^{BG}\frac{e^{-\frac{(\Delta t_i - \Delta t' - \mu_t^{BG})^2}{2(S_t^{BG}\sigma_i)^2}}}{\sqrt{2\pi}S_t^{BG}\sigma_i}] [(1-f_{\lambda BG})\cdot\delta(\Delta t') + f_{\lambda BG}\frac{\lambda_{BG}}{2}e^{-\lambda_{BG}|\Delta t'|}].$$

The fraction of background f_{BG}^i is calculated from the ΔE and M_b values for each event. The background shape parameters S_{BG}, S_t^{BG}, μ_{BG}, μ_t^{BG}, f_t^{BG}, λ_{BG} and $f_{\lambda BG}$ are determined from the fit. We use $S_{det} = 0.94 \pm 0.04$ in the $\overline{B} \to J/\psi \overline{K}$ analysis to account for slightly different kinematic properties from $\overline{B} \to D^* \ell^- \overline{\nu}$, $D\pi$ decays.

Figure 2 shows the Δt distributions and fit results for $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$ and $B^- \to J/\psi K^-$ events. Table 1 summarizes the measurement results. The main sources of systematic errors are uncertainties in the resolution function and the Δt dependence of the reconstruction efficiency. All results are preliminary.

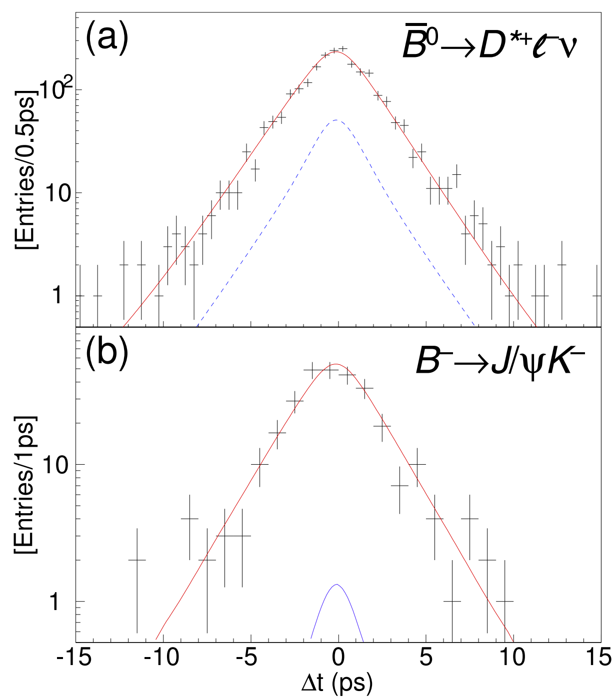

Figure 2: The Δt distributions and fit results for (a) $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$ and (b) $B^- \to J/\psi K^-$ events. The dotted curve represents the background.

Table 1: Summary of lifetime measurements.

(a) B lifetime measurements.

$\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$	$(1.50 \pm 0.06^{+0.06}_{-0.04})$ ps
$\overline{B}^0 \to D^{*+}\pi^-$	$(1.55^{+0.18+0.10}_{-0.17-0.07})$ ps
$\overline{B}^0 \to D^{+}\pi^-$	$(1.41^{+0.13}_{-0.12} \pm 0.07)$ ps
$\overline{B}^0 \to J/\psi\overline{K}^{*0}$	$(1.56^{+0.22+0.09}_{-0.19-0.15})$ ps
$\overline{B}^0$ combined	$(1.50 \pm 0.05 \pm 0.07)$ ps
$\overline{B}^0 \to J/\psi K_S$	$(1.54^{+0.28+0.11}_{-0.24-0.19})$ ps
$B^- \to D^{*0}\ell^-\overline{\nu}$	$(1.54 \pm 0.10^{+0.14}_{-0.07})$ ps
$B^- \to D^0\pi^-$	$(1.73 \pm 0.10 \pm 0.09)$ ps
$B^- \to J/\psi K^-$	$(1.87^{+0.13+0.07}_{-0.12-0.14})$ ps
B^- combined	$(1.70 \pm 0.06^{+0.11}_{-0.10})$ ps
$\tau(B^-)/\tau(\overline{B}^0)$	$1.14 \pm 0.06^{+0.06}_{-0.05}$
y_{CP}	$0.03^{+0.15+0.05}_{-0.18-0.08}$

(b) D lifetime measurements.

$D^0 \to K^-\pi^+$	$(414.8 \pm 3.8 \pm 3.4)$ fs
$D^0 \to K^-K^+$	$(410.5 \pm 14.3^{+9.7}_{-5.9})$ fs
$D^+ \to K^-\pi^+\pi^+$	(1049^{+25+16}_{-24-19}) fs
$D^+ \to \phi\pi^+$	(974^{+68+26}_{-62-18}) fs
D^+ combined	$(1040^{+23}_{-22} \pm 18)$ fs
$D_s^+ \to \phi\pi^+$	$(470 \pm 19^{+5}_{-7})$ fs
$D_s^+ \to \overline{K}^{*0}K^+$	(505^{+34+8}_{-33-12}) fs
D_s^+ combined	(479^{+17+6}_{-16-8}) fs
$\tau(D^+)/\tau(D^0)$	$2.51 \pm 0.06 \pm 0.04$
$\tau(D_s^+)/\tau(D^0)$	$1.15 \pm 0.04^{+0.01}_{-0.02}$
y_{CP}	$(1.0^{+3.8+1.1}_{-3.5-2.1})$ %

References

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